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MARTIN F. WEHLING

AFRL/RWWI
101 W. EGLIN BLVD
EGLIN AFB, FL 32542

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FINAL REPORT

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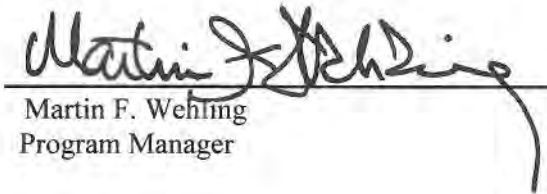
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Reset

Animals , especially flying insects, perform the tasks that we lump under the rubric “Guidance, Navigation, and Control” (GNC) , with coarse sensors and minimal apparent processing (compared to how we currently engineer systems), and yet their flight performance is very agile and robust. We would like to understand the details of these exquisite designs, in order to apply bio-inspired concepts to improve performance of human-engineered systems. Natural flying systems include bats, birds, and flying insects. While the vertebrate systems are certainly worth studying, the insect is a particularly appealing flying animal for study because insects are somewhat simpler than the vertebrate examples. For example, the insect sensors and neural system are somewhat simpler than the corresponding systems in the vertebrate fliers. The wing structure, sensors, and flight control, as well, are somewhat simpler than the corresponding vertebrate fliers, so the focus in the laboratory is primarily on flying invertebrates. Note all the systems mentioned are autonomous: they find food, mates, and avoid predators without a human in their GNC loops.

There are only a few insect systems that are being studied to the depth we need to develop systems-level understanding of their sensors, information processing, decision-making, and resulting flight path performance; some of these were originally studied for agricultural reasons (the locust *Schistocerca gregaria*, and the honeybee *Apis mellifera* are two relatively well-studied flying insects, but still without the requisite level of detail at the “engineering” level). While a few other species have been subjected to scrutiny (various flies, including mosquitoes for human health reasons, and some for agricultural reasons again, such as screw flies), only in recent years has the biology community begun to show significant interest in understanding the details of how the animals sense, process sensed information, and the overall mechanics involved in controlled flight. The purpose in setting up the RW BioSensors Laboratory as an in-house resource is to expand the experimental capabilities found in resource-limited academia for characterizing sensors and information processing in flying insects. We will select and study sensors/properties of species of interest, not only to provide more in-depth study of species already under study in academia, but also to study species that may be of particular interest to the AF but which are not studied in detail in academia. Comparing across species, genera, or families may be a particularly fruitful approach for biological investigations designed to elicit underlying basic principles; this sort of investigation is rarely seen in academia, and we will make these sorts of investigations whenever resources permit.

The current experimental emphasis in the RW BioSensors Lab, in rank order, is (1) Electroretinography [ERG], spectral and polarization, of compound eye and optic lobes, (2) ocellar characterization, (3) insect flight dynamics characterization, (4) ommatidial axis distribution characterization, (5) acoustic investigations, (6) neural cell morphology and connectivity, and (7) mechanosensors (halteres, filiform antennae, hair cells), including the various identified mechanosensing modes used by different insects in their antennae. At this writing, work is ongoing in the first four areas. Dr Ben Dickinson is investigating hair cells but not in this lab at this time. Dr Schrand is initiating an antennal survey that will initially focus on variations in antennal morphology, correlated with ongoing studies in academia on functionality.

Equipment currently in the lab includes a Zeiss Discovery V-12 stereo microscope; two Zeiss OPML-1 stereo microscopes (ophthalmic surgical microscopes purchased after working with them in Dr Holger Krapp's lab at Imperial College, UK); three NPI amplifiers (two extracellular channels each; one has an intracellular bridge amplifier and is modular for growth capabilities); an Oriel 260 1/4m monochromator; an Ocean Optics HR4000CG-UV-NIR spectrometer and associated DH 2000 spectrometer calibration device; various UV-visible light sources; a Faraday cage built to shield the ERG experiment; continuously variable neutral density filter (CVNDF) set up for spectral normalization of UV-visible light stimuli and comprised of identical counter-rotating NDFs; an internally designed ocellar stimulation rig (an automated Cardan arm with LED scene projection array, completing construction at this writing); a Sutter P-2000 CO₂ laser puller; a Leica microtome; two large optics benches (5 ft by 8 ft steel Newport tables) on compressed-air vibration-reducing mounts; one slightly smaller bench without air isolation system (3 by 8); and a still smaller older table without air isolation. Various computer interface boards by National Instruments have been installed in the two control computers. We have recently replaced our aging legacy oscilloscopes with two LeCroy LC584AL 1 GHz oscilloscopes. We have a variety of micromanipulators, including a pair of Märzhäuser piezo-driven motorized micromanipulators for intracellular measurements, and a pair of micromanipulators with hydraulic control bought to be used in the automated Cardan arm.

Facilities: The Bio-Sensors Lab (Dr Dennis Goldstein's old Optics Lab where he did optical surface characterization of various materials: polarization characterizations, spectral BRDFs, Mueller matrix elements, surface roughness characterization with a Zygo profilometer, etc. Dr Goldstein has moved his equipment to Eglin remote site C-86, but we still have access to Dr Goldstein and his optical characterization capabilities). We also use the old RW Chemistry Lab to store toxic chemicals and maintain our insectary; we have in fact renamed this lab the BioBehavior Lab since we have several large Plexiglas containers (parallelepipeds approx 1 m high by 1 m wide by 2 m long) we use as a preliminary confining space for videotaping insects in flight, to enable us to develop time histories of flight dynamics of insect species of interest in the laboratory environment preparatory to making these measurements outside. We have four time-synchronizable high speed Phantom black and white video cameras (Miro eX4, full 800 by 600 resolution at 1200 Hz frame rate), and a Sony handy-cam, provided by Johnny Evers, which we use to capture trajectory data and related information on flight path characteristics and control. We also have access to two Scanning Electron Microscopes, a conventional SEM (Jeol model 5900LV, with the capability to image up to 100,000X at 30,000eV) and an ESEM (FEI Quanta 200, with ancillary equipment including EDAX's Electron Backscatter Diffraction (EBSD) and EDAX's Energy Dispersive X-Ray Spectroscopy (EDS), that belong to our sister division RWM. The Advanced Guided Weapon Testbed (also known as KHILS) facility is near the Bio-Sensors Lab; Robert Barton is developing panoramic wide field of view ($>2\pi$ steradian) seeker stimulation (scene projection) capability there. Robert's current preliminary capability is in the visible region of the spectrum, but for compound and ocellar stimuli we would like to develop UV-blue-green high refresh rate, wide FOV stimulation capability for stimulating insect compound eyes and ocelli (and stomatopod compound eye midband sensors). The automated Cardan arm with its movable LED array, described later in the document, is a modest field-of-view version of Robert's WFOV projector for use in the Bio-Sensors lab testing insect visible sensors.

The original impetus behind setting up the lab was to be able to characterize optical properties of local insect eyes; this idea was broached with Prof Doekele Stavenga (Univ. Groningen, the Netherlands) with

the specific problem in mind of comparing local owlflies (*Ululodes spp.* and *Ascaloptynx*, both of which are crepuscular) with the well-known European owlfly *Libelloides macaronius*, which is diurnal in its habits, and has some interesting features about its optics, including a pronounced sulcus. (Kral, 2002; Fischer et al., 2006) The owlfly was also of interest due to its interesting flight behavior (it flies like a dragonfly) yet long, butterfly-like antennae (first observed about the time Tom Daniel, Sanjay Sane, and Mark Willis were showing *Manduca* could measure Coriolis forces with antennae oscillating in the wing downwash, Sane et al., 2007). With guidance from Prof Stavenga we began buying the necessary equipment that Dr Goldstein didn't already have available in the lab. In Feb 2008, Dr Stavenga and his student Primož Pirih visited for a week (an EOARD [European Office of Aerospace Research and Development] Window on Science [WOS] visit), and we configured an experiment on an optics bench to do electroretinography. The experimental setup was to be under computer control using WinWCP and LabView; a desktop IBM clone was pressed into service as a stand-alone computer platform for experimental computer control and data logging and analysis. In September 2008, Primož Pirih and Dr Gregor Belušič (Univ. Ljubljana) visited in a WOS visit, and we moved the experiment to a larger 5 by 8 vibration-isolated table, and upgraded parts. We collected and performed electroretinography on a number of local insects. Dr Belušič was very adroit in using WinWCP to analyze data.

There are two extremes for setting up this sort (ERG and similar) of experiment: at the one extreme (the pre-easily accessible computer way, or the "old-fashioned" way), each part of the experiment is done by hand. At the other extreme (the "modern" way), computer control of the experiment is maximized. The advantage of the old-fashioned way is that the experimenter develops an understanding of the animals and the animals' responses in the experiments, and the basic physics being used as stimuli in the experiment. The disadvantage is the slow rate of data collection. The advantages of massive computer control are that (1) data collection is to a large degree automated, minimizing the probability of human error in a complex experimental procedure, and (2) large amounts of data can be taken relatively rapidly; disadvantages include the danger of lack of development of clear insight into what is actually happening in the experiment, the requirement that the experimentalist learn to program in various computer languages (such as LabView and MatLab), and the fact that the experimentalist is now at the mercy of the vagaries of the computer industry. Which could be pretty dynamic and therefore disruptive, as operating systems evolve, and uncertainty develops as to what pieces of software and associated hardware will work together, and the complexities in incorporating multiple pieces of experimental hardware, and the software required to configure the experiments to run properly. We are, for example, using LabView, so people have to take the time to learn to program, check out, and implement the software. We followed Prof. Stavenga's and Primož' lead on this originally, and have expanded on it in that we are putting more components under computer control.

We currently have two stand-alone desktop computers in the lab for running experiments and logging and analyzing data. Both of these use Windows XP as an operating system. Both are configured with LabView and MatLab. No one in the lab is comfortable with WinWCP, and we all agree it would be much more satisfactory to convert from WinWCP to MatLab; we can write our own routines in MatLab, which we currently plan to do. We also have several stand-alone laptops to drive and record from specific instrumentation, in the field when necessary, including the Ocean Optics spectrometer, and the video cameras.

The staff (Mar 2012) includes Jennifer Talley (PhD from Mark Willis at Case in neuroethology), Dennis Goldstein (PhD, optical physics), Pam Card (BS, electrical and computer Engineering), LT Ryan Chapman (BS, physics), Ric Wehling (MS, physics) with assistance from Robert Barton (BS, EE), Tony Thompson (PhD, Mechanical and Aerospace Engineering). Dr Amanda Schrand (PhD, Materials Engineering), with experience in nanomaterials, recently joined the staff. Post doc Imraan Faruque from Sean Humbert's lab at University of Maryland is working on insect tracking for trajectory reconstruction, and senior NRC post doc John Douglass, who worked most recently at the Smithsonian lab in Panama, and before that at Prof Nick Strausfeld's at Univ. Arizona, is developing an automated technique for measuring inter-ommatidial angles. David Forester is working on insect tracking, and Rick Glattkke has been instrumental in getting the automated Cardan arm assembled and operating.

Several other labs, all in academia, doing work similar to the work the BioSensors Lab is being set up to do, have been visited around the world:

Dr Holger Krapp's lab (Imperial College, London), 2 different weeks in 2010 and two different visits in 2011. Holger's lab was originally set up to characterize Lobula Plate Tangential Cells: what are responses from the neurons under different stimuli, what is the range of responses? These are motion-detecting neurons and therefore require only monochromatic (green) appropriate motion stimuli. Holger has published a lot of neural morphology (stained neurons), but I haven't seen this being done in his current lab at Imperial. Holger also has interest in understanding how information from other sensors is fused with the information in the lobula plate, such as from the ocelli or the halteres; some of this work has been done at his old lab in Cambridge in association with Prof Simon Laughlin's lab there.

Prof Doekele Stavenga's lab (Groningen University, the Netherlands), a week in Nov 2007. Prof Stavenga's lab currently focuses on spectral responses of insect compound eyes, and understanding the basis of the spectral properties of different parts of the animal (butterfly wing scales, beetle elytra, bird feathers). Prof Stavenga's far-ranging interests include details of the physical optics of the eye, and the uses of pigments in the eye. Some work goes on with hair cells and lateral lines which is not relevant to this document. Prof Stavenga's lab is the "model" for our original ERG setup.

Prof Nick Strausfeld's lab (University of Arizona), last visited in Aug 2011 and only briefly then, but we will return and spend more time. Prof Strausfeld's lab does a lot of electrophysiology, and has done a lot of neural morphology; Prof Nick Strausfeld's lab routinely does morphology and fluorescent dye techniques when doing electrophysiology. A lot of Prof Strausfeld's interest is ultimately in the neuroarchitecture, as in the case of the Connectome he is developing for us for *Nasonia*, for which they need TEM and associated equipment and procedures.

Dr Jeremy Niven's lab (was at Cambridge, now at Sussex), visited briefly Sept 2010: Jeremy leans more toward the "old fashioned" hands on approach to electrophysiology, rather than a lot of computerized equipment. At this point in my understanding of the animals, their sensors, and experimental protocols, I can relate strongly to this approach. Implementation on the computers is a major distraction in trying to develop fundamental understanding: Less is more.

Visits to Prof Tom Daniel's lab (University of Washington), latest visit Sept 2011. Prof Daniel is building up an impressive lab facility in the basement of his building, replete with a wind tunnel capable of supporting impressive instrumentation, etc. Dr Michael Dickinson, recently returned to U WA from Caltech and Berkeley, is building up his laboratory in the same building housing Prof Daniel's lab. Prof Daniel's old lab, outside his office, usually houses a handful of graduate students doing very interesting work in diverse fields, including wing structures, mechanosensors, temperature distributions in active muscle tissue. I think there will be increased emphasis on integrated flight control with Dr Dickinson's influence at U WA. Dr Dickinson's lab is in place and up and running and apparently fully staffed in Sept 2011.

We have also visited Dr. Fabrizio Gabbiani's lab (Baylor), Dr Mark Willis' and Prof Roy Ritzmann's labs at Case Western, Prof. Justin Marshall's lab (University of Queensland), and Prof. Srinivasan (at ANU and more recently at University of Queensland).

Electroretinography (ERG) instrumentation: The current version of the ERG experiment is shown in figure 1. The basic intent is to characterize the spectral responsivity of different regions of the insect compound eye. As indicated in the figure, it should be also straightforward to insert a linear polarizer on a rotation stage, so that linear polarization sensitivity can be measured for different regions of the eye (e.g., the Dorsal Rim Area). Special Polaroid which transmits UV as well as visible is mounted in a stage which is computer controlled so the orientation of the incident linear polarization vector can be controlled. A device, consisting of a pair of counter-rotating continuously variable circular neutral density (CVNDF) filters, is being developed to insure the same flux in the stimulus is provided at all wavelengths. The CVNDFs are on rotational stages which are under computer control. The use of counter-rotating CVNDFs for this sort of application is an established technique. In principle, this set up could be used to characterize sophisticated optical systems such as the stomatopod compound eye, with multiple (up to 12 in the case of some stomatopods) spectral detector channels, and linear and circular polarization channels (by using quarter waveplates with the linear polarizers). Fig 2 is a photograph of the ERG setup in the lab in its current configuration, with the original make-shift Faraday cage. A fixture to hold the subject insect in readily reproducible position and attitude is being fabricated, to match the fixture being fabricated for the automated Cardan Arm configuration, described next.

Ocellar characterization instrumentation: The intent is to be able to characterize ocelli: fields of view, spectral responses, polarization sensitivities, temporal responses, etc., and to do this across the class Insecta to enable comparing order to order (family to family, species to species) which as far as I know has never been done. The approach for implementing the angular (az, el) location of the stimulus is described: It is a computer-controlled (automated) Cardan arm approach, involving Bishop Wisecarver's geared track mounts (figure 3) which Dr Goldstein has been using in his Optics lab for years for single axis sampling and control. The kinematic ("az-el") approach is the same as the kinematic approach being implemented by Daniel Schwyn and others in Dr Kit Longden's experimental setup in Dr Krapp's lab at Imperial College and will in the long run give the most complete data. (The difference is that in

the Imperial College approach the source array is moved around manually to predetermined fixed angular positions, whereas in our approach we are driving the angular locations with electric motors.) The ultimate version will involve a panel of LEDs under computer control, as well as computer control for the azimuth and elevation motors for positioning the LED panel. Parts for the automated Cardan arm design have been purchased and are being integrated at this writing; Robert Barton is developing the LED array drivers based on information from Daniel Schwyn. This ocellar characterization capability can support the Holger Krapp-Sean Humbert joint effort to compare attitude measuring instrumentation across several insects, as well as give insight into the design principles and applications of ocelli in the insect world. When configured with an appropriately large LED array, the Cardan arm device could also be used for stimulating the compound eye, which is in fact what the similar device (hardware in Fig 4) at Imperial College will be used for. We will use off-the-shelf “Reiser” LED chips (with origins in Dr Michael Dickinson’s lab and currently being used in other labs, including Dr Holger Krapp’s lab; see Reiser and Dickinson, 2008), which are built from units of 8 by 8 LED arrays with 4 mm pitch, as the basic stimulus; in our current plan for the automated Cardan arm, the face of the Reiser chips will be approximately 15.8 inch from the subject insect eye, so in the preliminary configuration the Reiser LEDs subtend about $10 \text{ mrad} = .57 \text{ degree}$. As Robert Barton develops the drive software and hardware we will see what sorts of temporal response we can get out of the system; we would like at least 250 Hz. (Robert will be using control software from Dr Steven Fry’s lab in Zurich initially.) A photograph of the device taken in early March 2012 is presented in Fig 5. We are awaiting delivery of a stand designed to hold the insect and the micromanipulators, and configuration of the array-driving software, in order to begin shake-down use of the configuration.

Environmental measurements: it is necessary to understand what the natural environmental conditions the test specimen normally operates in, in order to understand what the test results mean. We are developing an instrumentation suite that can be used when capturing specimens in the wild that will measure temperature, relative humidity, and light level. In addition to characterizing the ocelli in the lab environment, we also need to understand the natural environment in which the ocelli operate, so we can make the lab environment as realistic as possible to insure the ocelli are operating under design conditions when characterized. Sky brightness is absolutely necessary, and spectral and polarization properties of the sky brightness are highly desired. We are acquiring a pyranometer to take the necessary measurements. This basic idea should be expanded to characterize all relevant parameters in the environment affecting the insect and its sensors and processing performances. We are looking at ways to monitor the weather conditions at Eglin range C-86, where we catch many of the insects we measure in the laboratory. Our first foray in this area will be to measure temperature, since the ambient temperature is so important to insect behavior; we would also like to measure wind speed as it determines when the insects fly and therefore are subject to capture.

Flight path dynamics: consider the sensors available to flying insects to measure attitude and attitude control; all flying insects are not configured with the same sensor suites: some have 3 ocelli, some 2, some none. True flies (Diptera) have halteres that provide gyroscope-type inputs through sensing Coriolis forces (Thompson et al., 2009); flying insects from other orders (non-Dipteran) in general do not. The number of lobula plate tangential cells that respond to optic flow patterns differ for different

insects; they vary wildly even just among families of flies (Buschbeck and Strausfeld, 1997). The number of ocelli in flies appears to be roughly inversely proportional to the number of VS cells. Why these differences? One possible explanation is that the animals have different flight path dynamics, and the differences in sensor suites reflect the differences in flight path dynamics. There are very few publications in the literature on flight dynamics that could be used to address this question; the classic papers are Collett and Land (1975), Land and Collett (1974), and Wagner (1986). Recently Prof. Martin Egelhaaf's group at Bielefeld and Dr. Hans van Hateren, who collaborates with Prof Egelhaaf's group, have published in this area. We would like to investigate this idea for insects we deem of interest, and so are developing the capability to measure flying insect flight path dynamics in the lab, involving multiple high speed high resolution cameras for data capture. Johnny Evers has provided an initial set of cameras, four Phantom Miro EX4s. We have a grant in place with Dr Sean Humbert at University of Maryland to provide post-docs to develop, refine, and use the facilities in RW (Dr Humbert's group does this sort of research at U Maryland). The resulting capability can support testing the Mode Sensing Hypothesis (Krapp, Taylor, et al., 2012). Tasks to be addressed include camera system calibration, autotracking, and trajectory reconstruction in 3 or 6 (or more) degrees of freedom. While it is desirable to have this capability inside the laboratory, it would be much more desirable to have it outdoors where the animals can experience natural scene structure, natural lighting conditions, and are not inhibited by lack of accessible space. Additional degrees of freedom represent additional data such as body part articulation and wing flexing, which would be available with sufficient temporal and spatial resolution in the image sequences. Eventually, it would be useful to utilize the Reid Harrison- Fabrizio Gabbiani electrophysiology-myology telemetry backpack chip we had developed a few years ago (Harrison, Gabbiani, et al., 2010), to take measurements from neurons and muscles during free flight and correlate with the camera-derived trajectory data.

Ommatidial angle distribution determination: there are very few ommatidial angle maps in the literature. They are difficult and tedious to do by hand. On the other hand, they provide insight into where the insect has acute regions in its field of view, and therefore have implications for visual neuroethology and the Graham Taylor-Holger Krapp-Sean Humbert Mode-Sensing-Hypothesis (MSH). Prof. Doekele Stavenga and I had discussed, several years ago, the possibility of setting up such a capability. The need still exists for an automated (computer-controlled) approach to decrease the human tedium. The key problem is to develop a suitable sensor to determine when the instrument is on the ommatidial optical axis. This sensor may have to be species unique. (e.g., Prof. Stavenga showed me that we can get nice eyeshine on reflection from certain butterflies, but that reflection phenomenology is not available with robberflies. Prof. Stavenga also demonstrated that the assumption that the optical axis of an ommatidium passed through the center of the facet, and was normal to the facet, was not true in general: it will be necessary to develop an automated technique that will determine when the sensor is on the optical axis of each ommatidium. This is easy for certain butterflies because of the reflected eyeshine due to the tapetum. But not easy for a lot of other interesting animals, which don't have tapeta.

Acoustic investigations: when hunting flying insects in the field, it seems that different insect species can be distinguished by the details of the acoustic signature. It would therefore be interesting to develop a device that would, given a suitable data base of flying insect acoustic signatures, identify flying

insects encountered in the field. There is some limited acoustic signature data in the literature. Acoustic signatures are also of interest for studying halteres, since the haltere oscillation frequency is the same as the wing beat frequency. (Dr. Tony Thompson's dissertation involved analytical studies of halteres, so measured haltere frequencies would be of interest for further analysis; Thompson, Wehling et al., 2009). A high school summer student (Josh Treloar) came our way in 2009, and we gave him a microphone and a laptop with Fourier transform routines on it, and had him measure acoustic signatures of flying insects. Insect acoustic sensors also turn out to be interesting; there are two types: filiform, which involve "hair cells" on the insect antennae, respond to the "particle motion" in the near sound field, and occur on nematoceran flies such as the Culicidae; and tympanal sensors, which respond to the far field pressure variations, and occur on brachyceran flies, such as *Ormia*, and can measure microsecond (!) differences in arrival times. The basic sensor for the filiform antennae is Johnston's organ, a mechanosensor that is found in the antenna pedicle and consists of chordotonal organs and Böhm bristles. This interesting sensor is exploited by different insect species for a variety of purposes in addition to (near field) acoustic detection, including airflow and gravity detection in some species.

Subject animals. In Florida we are blessed with a plethora of potential study subjects. Interesting insects emerge in mid-March, typically, and we have a variety of insects (with different sensor details, different neuroethology, etc) available until mid to late October. For a supply of specimens in the winter months (Nov – Feb) we have established an insectary, and currently are maintaining a colony of Sarcophagids as "lab rats." (We are on generation 11 of the current strain at this writing.) If desired we could include other common lab rats, such as *Calliphora*, *Manduca*, etc.

Collaborations: The original motivation was to set up ERG to facilitate comparing New World Owl Flies (Florida's 4 species) compound eye characterizations to Old World (probably to *Libelloides macaronius*, previously known as *Ascalaphus macaronius*); still desire to do so but it's been very difficult to catch owlflies near Eglin: they are crepuscular and have been difficult to catch to date. Although apparently there's no problem in Texas, based on discussions with Dr John Oswald and his doctoral student Joshua Jones at Texas A&M. We hope to solve capture problems with local *Ululodes* species by June 2012 and make meaningful measurements that can be used to compare to *Libelloides*. As far as capture problem, based on capture data painfully assembled in summers of 2010 and 2011, there appears to be a strong correlation between frequency of capture and phase of the moon: multiple insects are captured in crepuscular conditions associated with the full moon; it is much harder to capture even single insects when the lunar phase is significantly different from full. There is also a wide variety of other insects with interesting eyes to be captured locally and optical systems characterized.

With Dr Willard Larkin's funding Drs Sean Humbert and Holger Krapp to characterize LPTCs (and ocelli) and compare across Dipteran families, there are opportunities for us to participate, especially since we find it difficult to get large numbers of samples of large Florida robberflies to Dr Krapp's lab in the UK in decent condition for making measurements. Dr Krapp had suggested we develop the capability to characterize the ocelli, independently of but simultaneously with, Dr Jennifer Talley's proposing to do exactly that for her NRC post-doc research here.

We have provided multiple batches of 3 species of Florida robberflies to Jess Fox in Dr Tom Daniel's lab; through use of overnight UPS they arrive alive and can recover and give presumably valid measurements (*Laphria*, *Diogmites*, and *Mallophora* are the three large species we have sent). We have tried to

provide to Dr Krapp's lab but the only certain way to get these across the Atlantic in reasonable condition is to hand carry them. Express mail doesn't get it done quickly enough.

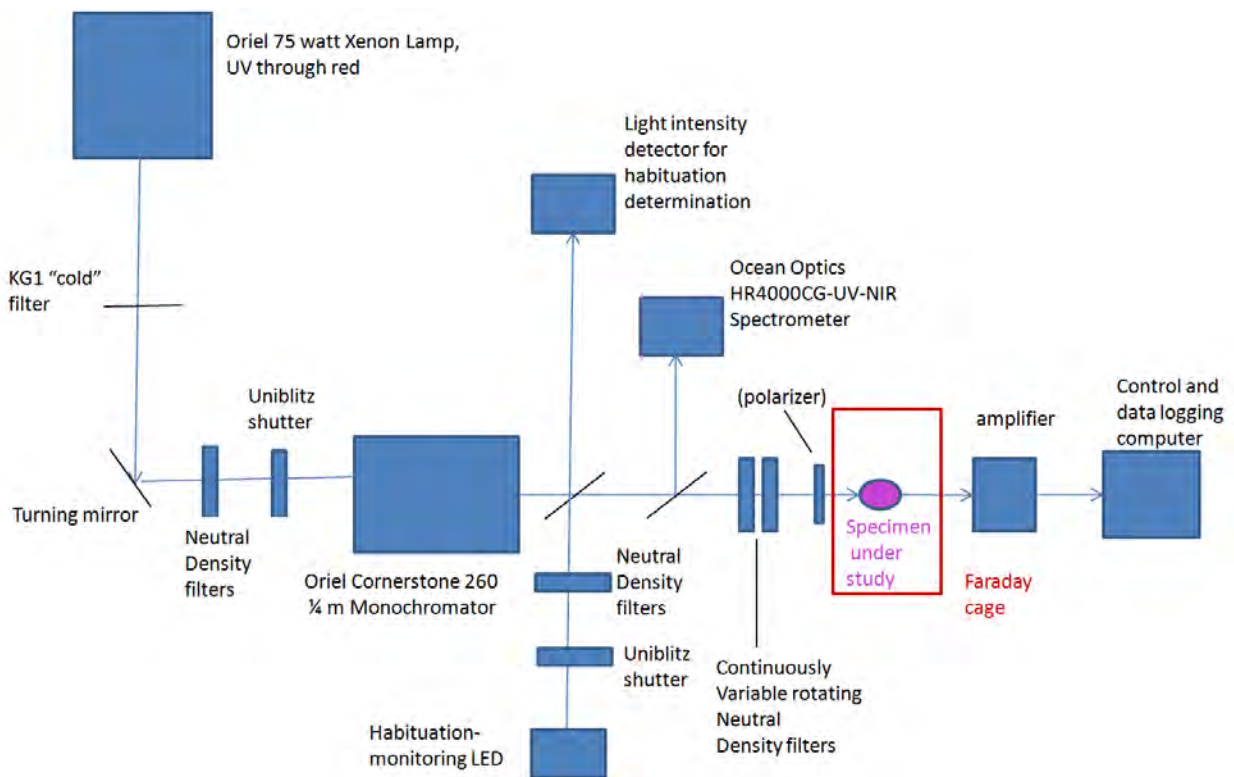


Figure 1. Electrophysiology set up. The latest development is the construction of the CVNDF spectral intensity controller, which is currently being calibrated.

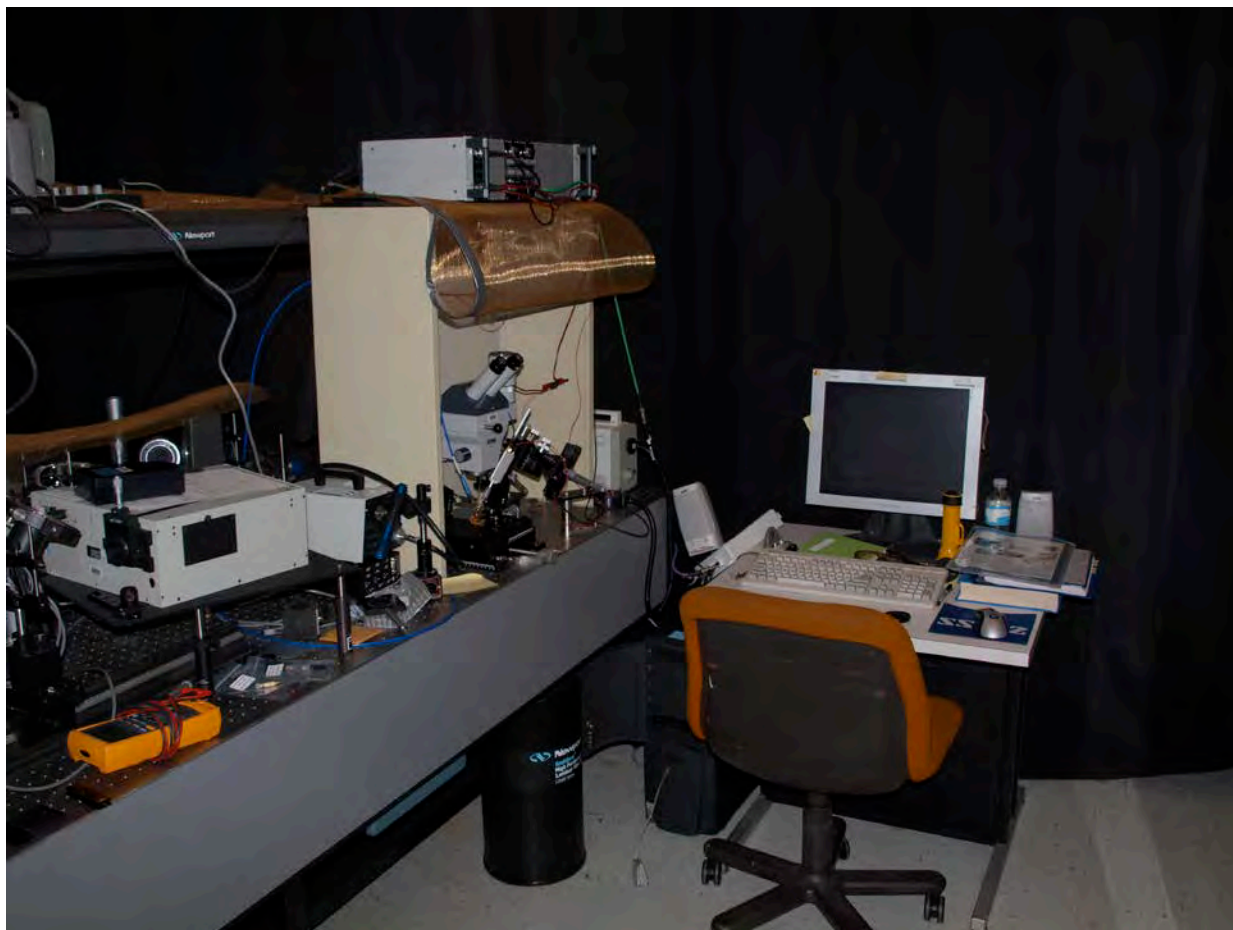


Figure 2: Photograph of the ERG set up. Monochromator on the left, work station with dissecting microscope in the old Faraday cage in center of photograph. NPI amplifier atop the Faraday cage. The addition of a linear polarizer will permit investigation of polarization sensitivity.

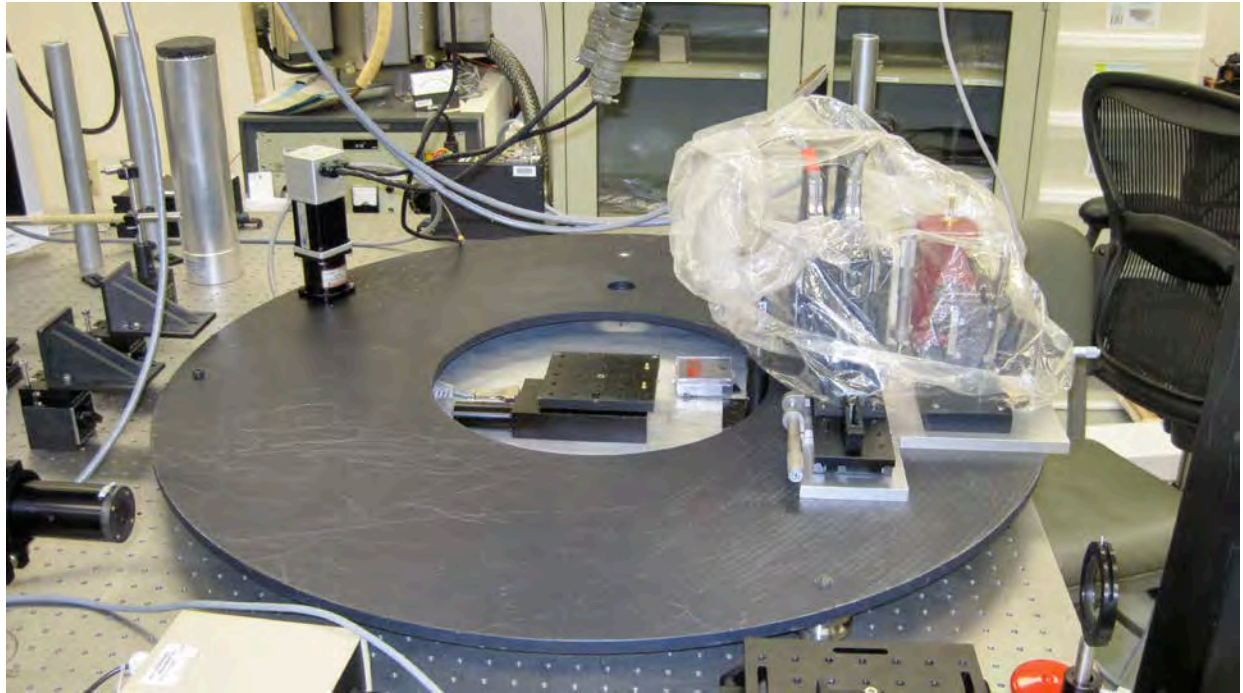


Figure 3. The table for azimuthal control of the automated Cardan arm stimulator. The vertical device at the back left of the rotating disc is the drive motor, which engages directly with gear teeth underneath the rotating disc to drive it in azimuth. This is the same design Dennis Goldstein has used successfully in his optical characterization lab for years. The diameter of the black base disc is 1 meter. The support structure under the black base disc has channels cut through it for electrical, pneumatic, etc feed-throughs. The elevation mount is described in the caption to figure 4.



Figure 4. Daniel Schwyn's LED stimulation box in the foreground; the az-el mount in Dr Kit Longden's lab for stimulating compound eyes in the background at the right. Daniel's source box will fit in the movable steel receptacle visible in the az-el mount. We are developing a similar LED stimulator that can be mounted on a motorized elevation track that will arch over and be mounted on the azimuth disc in figure 3, comprising a Cardan arm. Daniel and Kit work in Holger Krapp's lab at Imperial College.

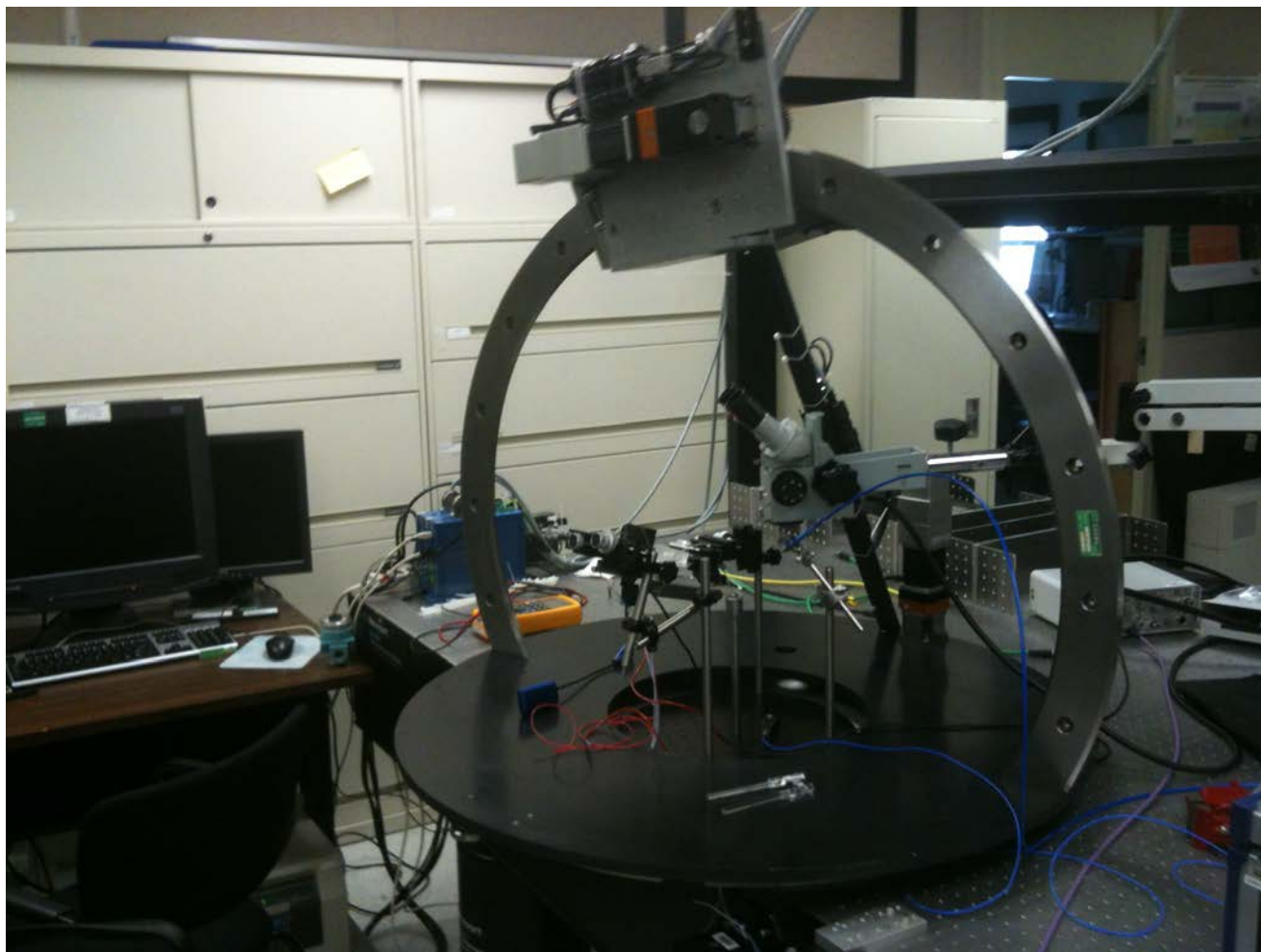


Figure 5. Photograph of the automated Cardan Arm. The 1 meter disc (photo in Fig 3) is the bottom piece; an electric motor mounted perpendicular to the disc drives the source array in azimuth. The Bishop-Wisecarver stainless steel elevation ring was cut to fit on the disc in AFRL/RWM's Rapid Prototype Fabrication Facility, and carries the carriage (pictured at the top of the elevation ring) with its drive motor and the LED array (which will be mounted on the face plate), looking down on the central opening in the azimuth disc in the figure. The opening in the azimuth disc contains the base for the micromanipulators which will hold the specimen under test at the center of rotation for the two discs. The adjustable diagonal strut is for stability, if necessary. The two blue boxes on the corner of the optics bench behind the structure are the controllers for the two electric motors that drive the azimuth disc and the carriage location on the elevation disc. Stimulation for the experiment will be provided by the blue-clad UV-vis optical fiber in the figure.

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